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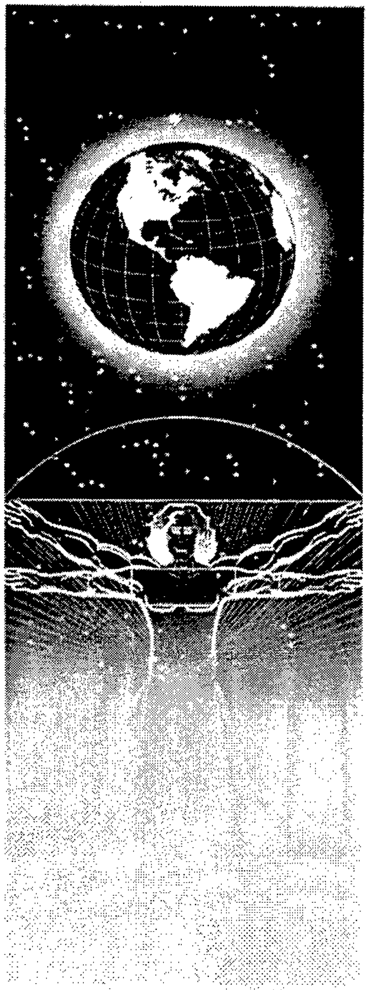

UNITED STATES AIR FORCE RESEARCH LABORATORY

Vertical Impact Tests of the Panoramic Night Vision Goggle

Chris E. Perry

November 1998

Interim Report for the Period September 1998 to November 1998

Approved for public release; distribution is unlimited.

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This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE DIRECTOR

Roger L. Stork

ROGER L. STORK, Colonel, USAF, BSC
Chief Biodynamics and Protection Division
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Air Force Research Laboratory

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The Panoramic Night Vision Goggle (PNVG) was developed to provide an ultra-wide field of view over conventional NVGs; however, the PNVG, when attached to a standard USAF flight helmet, alters the helmet's inertial properties. These altered properties could potentially induce neck injuries during ejection. An experimental effort was conducted to measure the biodynamic response of an Advanced Dynamic Anthropomorphic Manikin (ADAM) subjected to simulated catapult dynamics while wearing the Panoramic Night Vision Goggle (PNVG). A series of vertical impacts were conducted with the PNVG using the AFRL/HEPA Vertical Deceleration Tower (VDT). The VDT impact test pulses were a nominal 10 G peak half-sine waveform with an approximate rise time of 72 ms. The effects of inertial property differences of the PNVG helmet system as compared to a baseline HGU-55/P were evaluated and found not to increase the risk of injury during the catapult phase of ejection with an ACES II seat when compared to a current operational helmets. Dynamic evaluation of the PNVG helmet using 10 G vertical impacts indicated that it will not induce neck loads greater than established VDT human tolerance values. Dynamic evaluation also found no structural failures to the PNVG mounting points.

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PREFACE

An experimental effort was conducted to measure the biodynamic response of an Advanced Dynamic Anthropomorphic Manikin (ADAM) subjected to simulated ejection seat catapult dynamics while wearing the Panoramic Night Vision Goggle (PNVG) helmet-mounted night vision system. The vertical impact tests and data analysis described in this report were accomplished by the Biodynamics and Acceleration Branch, Biodynamics and Protection Division, Human Effectiveness Directorate of the Air Force Research Laboratory (AFRL/HEPA) at Wright-Patterson Air Force Base OH. The tests were conducted at the request of Mr. Jeff Craig and 1Lt Tim Jackson of the Visual Display Systems Branch (AFRL/HECV). The PNVG test article was supplied by AFRL/HECV. Test facility and engineering support at AFRL/HEPA was provided by DynCorp, Inc., under contract F33601-96-DJ001.

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INTRODUCTION

New and improved flight control systems are allowing pilots to fly mission profiles that are higher, faster, or that are at very low altitude. To improve pilot performance during these missions, the Air Force has been investigating the use of helmet-mounted visually coupled systems such as night vision devices or goggles, and helmet-mounted display systems. However, these systems which are designed to improve performance, may increase the potential for neck injury during emergency escape from aircraft using a ballistic ejection seat. The increase in the potential for neck injury is due to the use of the helmet as a platform which can alter the helmet's inertial properties (helmet weight, helmet center of gravity, helmet moment of inertia) (Perry, 1993; Buhrman and Perry, 1994). The altered helmet weight can potentially increase the axial load in the cervical vertebrae, and the altered cg can potentially increase the moment or torque induced in the cervical vertebrae. An increase in each of these loads, or a combination of both, may increase the potential for neck injury.

BACKGROUND

Literature reviews have shown past research efforts concentrating on helmet weight relative to muscle fatigue in both normal- and sustained-G flight environments. Helmet weights in the range of 4 to 5 lbs maximum have been recommended (Phillips, Petrofsky, 1983). Only recently (last 8 years) has research been initiated to examine the relationship between helmet inertial properties (weight and cg) and the biomechanics of the neck during the impact acceleration experienced during emergency ejection. An ad-hoc working group based at Wright Patterson AFB was established to review past and current research efforts, accident statistics, and published literature as it related to neck tolerance and neck injury. The reviews were conducted in order to develop criteria on maximum head supported weight and altered cg in order to minimize neck injury during ejection. A report was generated summarizing the Head and Neck Criteria developed by the working group. Subsequently, a research effort was conducted to investigate parametric shifts in helmet inertial properties on human biodynamic response during vertical impact. Tests were conducted at various impact acceleration levels and with variable weight helmets to expand the database on neck tolerance. Study results indicated, that relative to the occipital condyle, compressive loads of approximately 260 lbs, shear loads of approximately 80 lbs, and M_y moments in forward flexion of approximately 400 in-lb were well tolerated by human volunteer subjects (Perry, 1996). These results have been used, in part, to establish current human neck load tolerances.

The Panoramic Night Vision Goggle (PNVG) was developed to provide an ultra-wide field of view over conventional NVGs; however, the PNVG, when attached to a standard USAF flight helmet, alters the helmet's inertial properties. Prior to use in F-15s as part of an operational utility evaluation, test data were needed for presentation to a safety executive board to evaluate PNVG effects on neck loading during the catapult phase of ejection. As a result, an experimental effort was conducted to measure the biodynamic response of an Advanced Dynamic Anthropomorphic Manikin (ADAM) subjected to simulated ejection seat catapult dynamics while wearing the Panoramic Night Vision Goggle (PNVG) helmet-mounted night vision system. The PNVG is shown in Figure 1 and Figure 2.

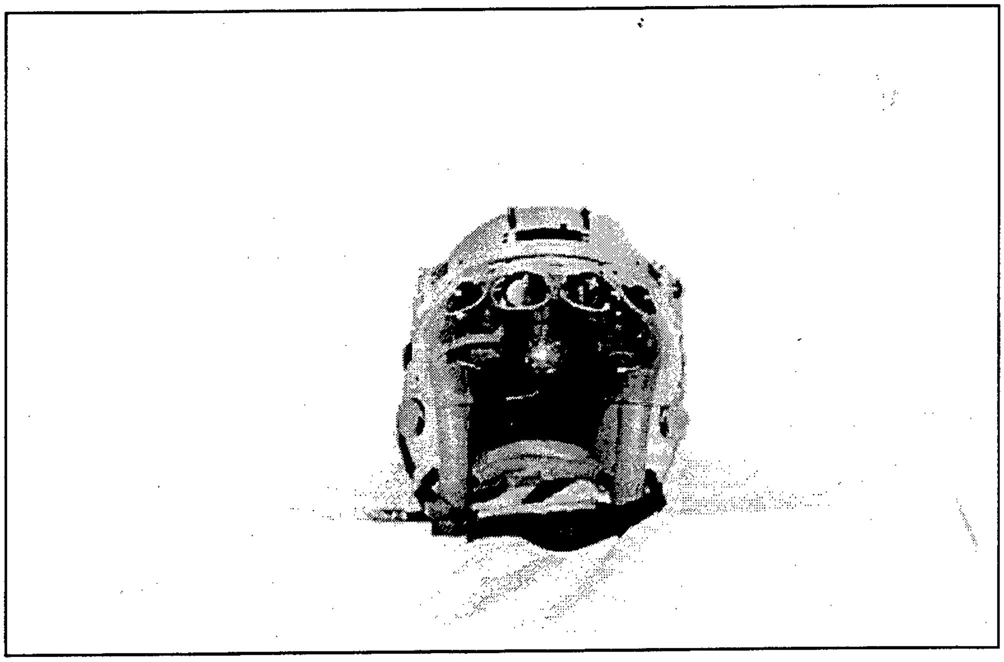

Figure 1. Front View of Panoramic Night Vision Goggle Mounted on HGU-55/P Helmet

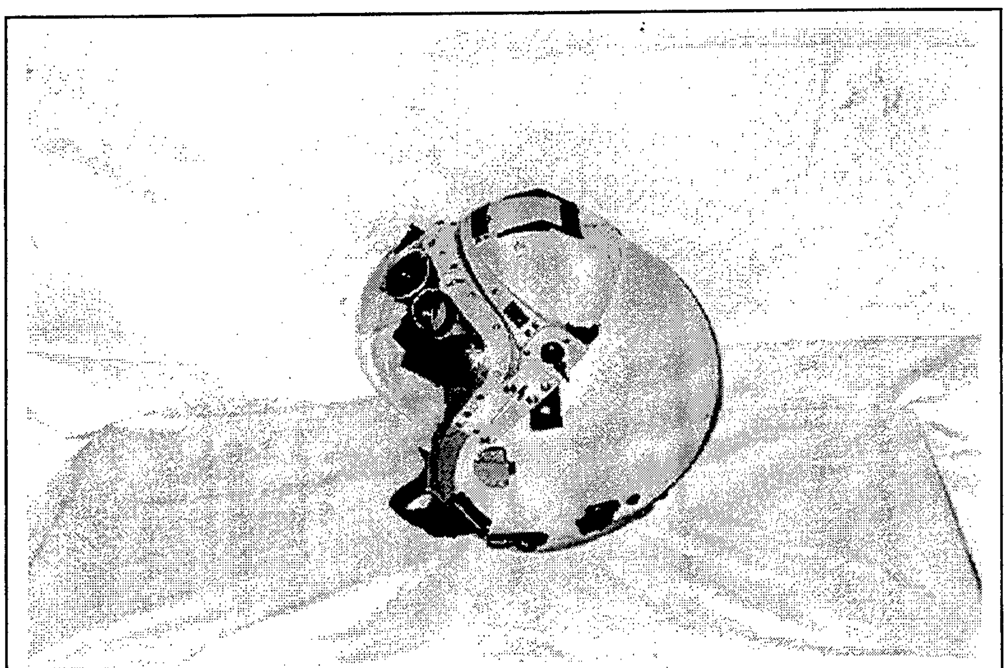

Figure 2. Side View of Panoramic Night Vision Goggle on HGU-55/P Helmet

METHODOLOGY

A series of vertical impacts were conducted with the PNVG to simulate the catapult phase of an ACES II ejection. The vertical impacts were conducted on the AFRL/HEPA Vertical Deceleration Tower (VDT) shown in Figure 3. The VDT impact facility is composed of two vertical rails and a drop carriage. A generic test seat is attached to the vertical face of the carriage in an upright position. To conduct a vertical impact test, the carriage is raised to a specified height from a resting position, and is then released and allowed to enter a free-fall guided by the rails. A plunger mounted on the rear of the carriage is guided into a floor-mounted cylinder filled with water located between the vertical rails. A +Gz deceleration pulse is produced at the carriage when water is displaced from the cylinder by the plunger. Varying the drop height, which determines the peak G level, and varying the shape of the plunger, which determines the rise time, controls the shape of the VDT's output acceleration pulse.

The VDT impact test pulses were a nominal 10 G peak half-sine waveform with an approximate time to peak acceleration of 72 ms (Figure 4). The VDT 10 G impact produces peak torso accelerations with human subjects that are equivalent to the peak torso accelerations experienced by the ejectee during the catapult phase of an ACES II ejection. Figure 4 also shows the typical corresponding vertical acceleration of a subject's head. To assure consistent impact acceleration test conditions, the drop height, test carriage mass, and plunger type were the same for all experimental test conditions during the evaluation.

All tests were conducted with the seat back perpendicular to the seat pan, and with the impact vector in line with or parallel to the seat back plane (0° forward angle). The ACES II seat has the back plane at 3.5° forward angle from the ejection rails. Previous work on the VDT has shown that a seat back angle of up to 5° forward of the impact vector does not significantly affect the human dynamic response during vertical impact (Perry, Bonetti, and Brinkley, 1991)

All tests were conducted with a large Advanced Dynamic Anthropomorphic Manikin (ADAM). The manikin was instrumented to record both linear and angular head and chest accelerations, and multi-axial neck forces and torques relative to the occipital condyle. The manikin was dressed in a flight suit and restrained with a standard USAF double shoulder strap and lap belt combination. Prior to each test, the restraint system was pre-tensioned to 20 □ 5 pounds using load cells positioned at the shoulder strap termination point behind ADAM's shoulders, and at the right and left lap belt anchor points located beside ADAM's hips. The manikin's arms were restrained on the upper legs using Velcro straps. The lower legs of the manikin were also restrained with Velcro straps to the front of the seat fixture. This is also shown in Figure 3.

In addition to the acceleration sensors, each helmet (baseline and PNVG) and mask was instrumented with IR LEDs which were tracked by the SELSPOT Motion Analysis System. The SELSPOT system tracks the LEDs to determine helmet and mask displacement during the impact. Data were collected at 1000 samples per second. The SELSPOT LEDs are shown in Figure 5. In addion to the SELSPOT data, a high speed KODAK video camera running at 500 frames per second was also used.

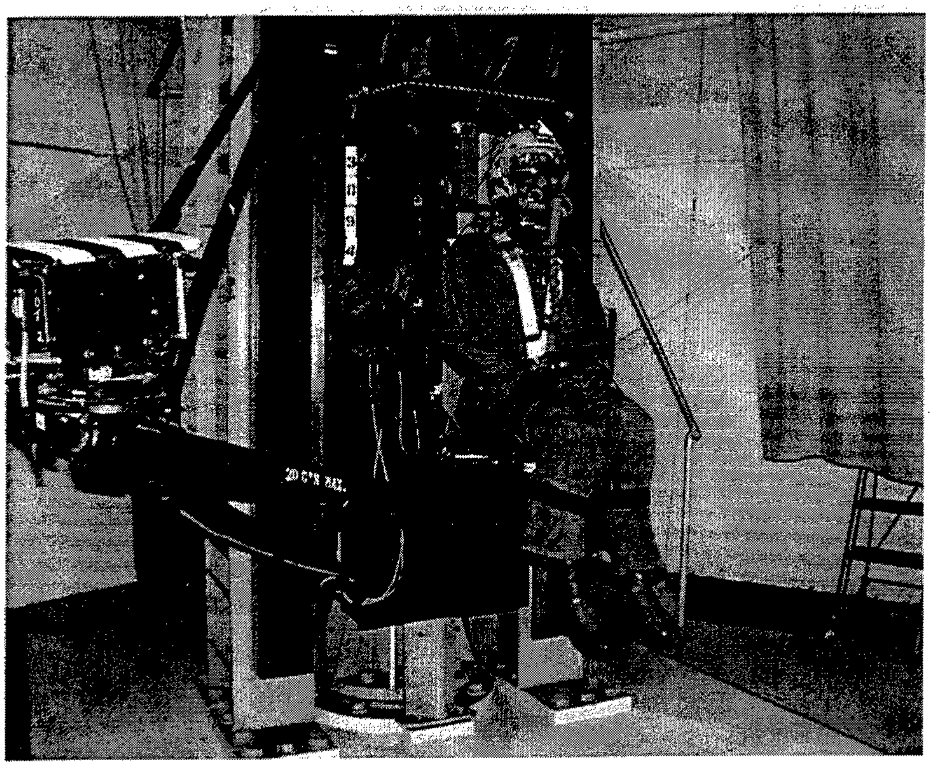

Figure 3. AFRL/HEPA Vertical Deceleration Tower

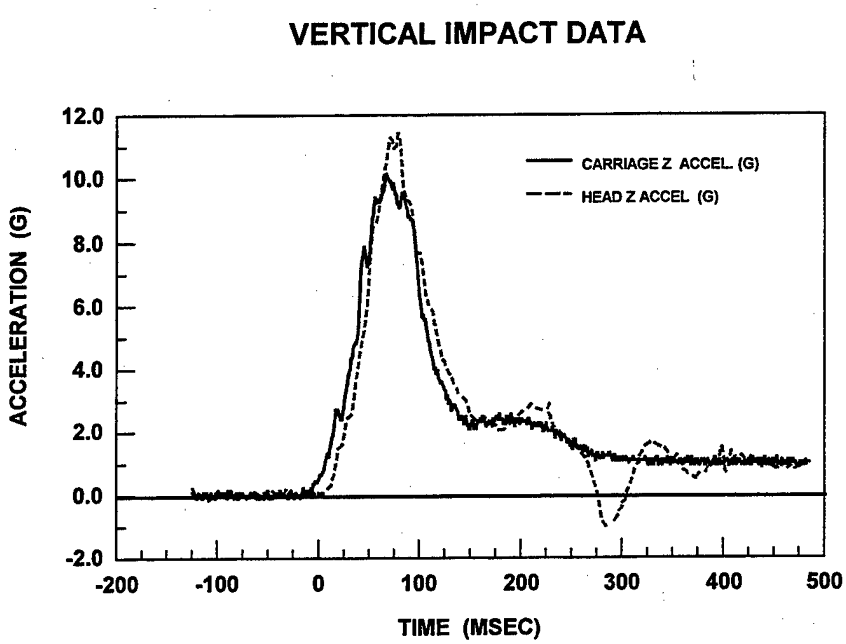

Figure 4. VDT Impact Pulse and Human Head Acceleration Response

All measured head acceleration data and load data are relative to the anatomical axis system of the ADAM headform. The anatomical axis (Figure 5) is defined by three vectors: (1) the positive y-axis is a vector from the right to the left tragion (Tragion is defined as the superior point on the flap of tissue anterior to the ear canal); (2) the positive x-axis is a vector normal to the y-axis and extending from the y-axis to the infraorbitale (infraorbitale is defined as the lowest point on the inferior bony ridge of the eye socket), the vector is then translated to the mid-line or sagittal plane of the face; and (3) the positive z-axis is a vector normal to the intersection of the y-axis and the x-axis and projects through the top of the head. The intersection of the three coordinate axes defines the coordinate origin of the anatomical axis system. The occipital condyle, to which the calculated neck loads are referenced, is found approximately 1" down and 1" aft of the anatomical axis origin (Perry and Buhrman, 1996).

Measurements of all torso acceleration data were made relative to the anatomical axes of the human body. The anatomical axes are defined with the z-axis being along the axis of the spine, the x-axis being fore/aft relative to the head or torso, and the y-axis being lateral or from side-to-side relative to the head or torso.

The helmets (baseline and PNVG) and masks were instrumented with infrared LEDs which were tracked by the SELSPOT Motion Analysis System. The SELSPOT system tracks the LEDs to determine helmet and mask displacement during the impact. Data were collected at 500 samples per second. The SELSPOT LEDs are shown in Figure 6. In addition to the SELSPOT system, a high-speed Kodak video camera running at 500 frames per second was used for visual documentation.

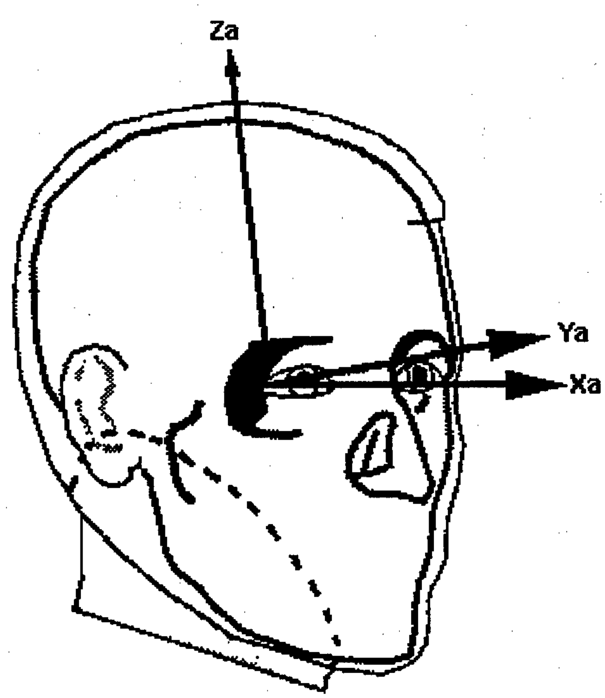

Figure 5. Head Anatomical Axis System

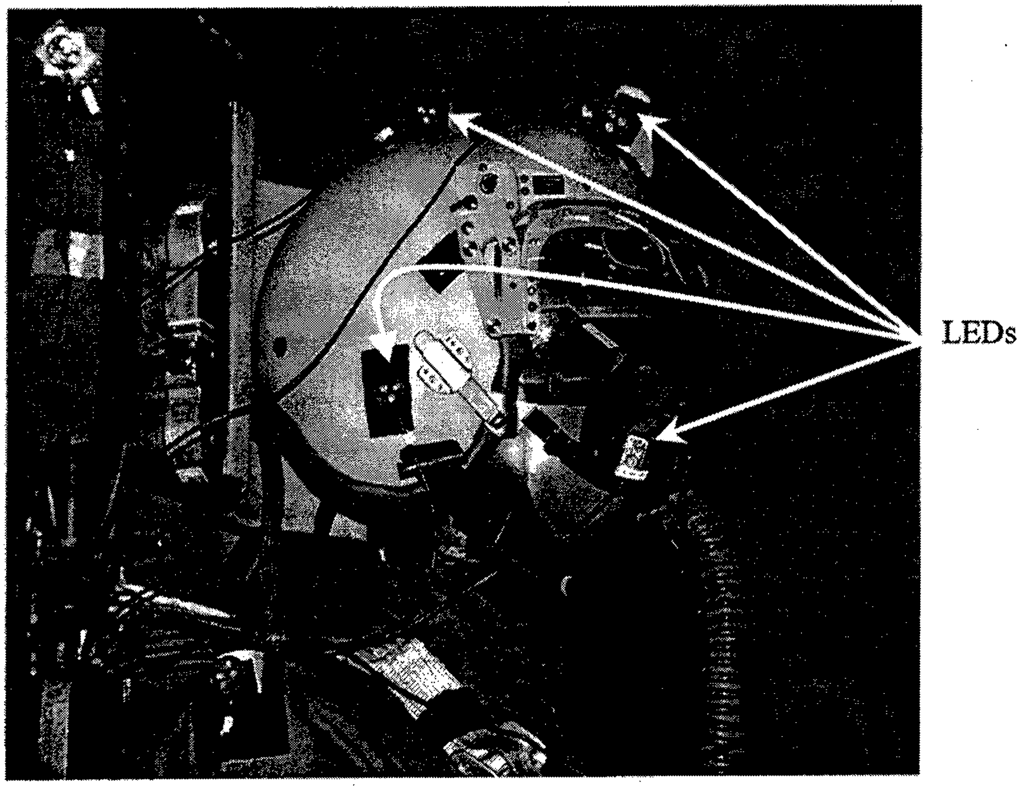

Figure 6. Position of SELSPOT LEDs on Helmet and Mask

Five tests were conducted with the baseline HGU-55/P helmet, and five tests were conducted with the PNVG helmet system. An MBU-20/P mask was used for the PNVG tests, and an MBU-12/P mask was used for the baseline helmet tests. Each helmet was fitted with removable leather soft-back earcups. All tests were conducted at peak acceleration of 10 G. Table 1 provides the test matrix for the helmet systems.

Table 1. PNVG Impact Test Matrix

Test Cell	Impact Level	No. of Impacts	O_2 Mask	Helmet System
A	10 G	5	MBU-12/P	HGU-55/P
B	10 G	5	MBU-20/P	PNVG

The specific PNVG unit that was tested was PNVG Configuration #1. This configuration was mounted on a light weight HGU-55/P helmet with the Integrated Chin/Nape Strap. The configuration included a clear slotted visor (Frame #002), the PNVG (Unit #0001), the Removeable Electronics Module or REM (Unit #003), a size medium/narrow MBU-20/P mask. The configuration also included 2 AAA batteries, a mock-up head tracker, and six inches of the Power/Communication cable off the back of the helmet.

Inertial properties were measured on each helmet set-up using the AFRL/HEPA Biofidelity Testing Laboratory. The Biofidelity Testing Laboratory conducts measurements on humans, human surrogates, and personal equipment for the purposes of developing databases to be used in design, analytical modeling, and evaluation. The Biofidelity Testing Laboratory has facilities to measure: inertial properties of humans, manikins, manikin segments, seats, and head-mounted or other equipment; structural properties of manikin joints, necks and other deformable objects; and fragment strike characteristics.

RESULTS

Inertial properties were measured for each helmet set-up to compare changes in weight, center-of-gravity, and momet-of-inertia caused by the addition of the PNVG to a helmet (Table 2). The PNVG system inertial property data were compared to the criteria shown in Figure 7. The criteria indicates that when the center-of-gravity of a helmet system combined with a Large ADAM headform is located within the limits identified by the boxes in the plot, and also meets the stated weight limits indicated for each ejection seat, the helmet system will produce compressive neck loads no greater than the loads produced by current operational helmets during the catapult phase of ejection. The weight limits are defined at the top the plot. The axes of the plot coincide with the anatomical coordinate axes of the head. The zero-zero point on the plot coincides with the origin of the anatomical coordinate axes of the head.

The PNVG helmet system measured on an ADAM head had a center-of-gravity that was within the inner criteria box, but the helmet system exceeded the weight limit by 0.31 lb. The additional weight was evaluated in two ways. The first evaluation looked at the effect of the additional weight on the estimated compressive neck load during vertical acceleration using previously identified relationships between helmet inertial properties and compressive neck loads developed at Wright Patterson AFB with the VDT (Perry and Buhrman, 1996). The additional weight was found to increase the compressive neck load by less than 5%, and was still less than tolerable loads experienced by human volunteers on the VDT.

The second evaluation looked at the static torque relative to the occipital condyle of the PNVG system. The static torque values were compared to the maximum static torque value (approximately 120 lb-in^2) generated by the four corners of the outer criteria box. The PNVG was found to have a static torque value 93 lb-in^2 which is less than the criteria's maximum static torque value.

Table 2. Helmet System Inertial Properties

Item	Weight (helmet only) (lbs)	Center of Gravity (in)			Moment of Inertia ($lb\text{-}in^2$)		
		x	y	z	Ix	Iy	Iz
ADAM Headform	9.52	-0.49	-0.08	0.89	76	83	51
ADAM, HGU-55/P, MBU-12/P	12.48 (2.96)	-0.36	-0.06	0.92	134	133	95
ADAM, PNVG, MBU-20/P	14.70 (5.31)	0.23	-0.01	1.20	138	189	168

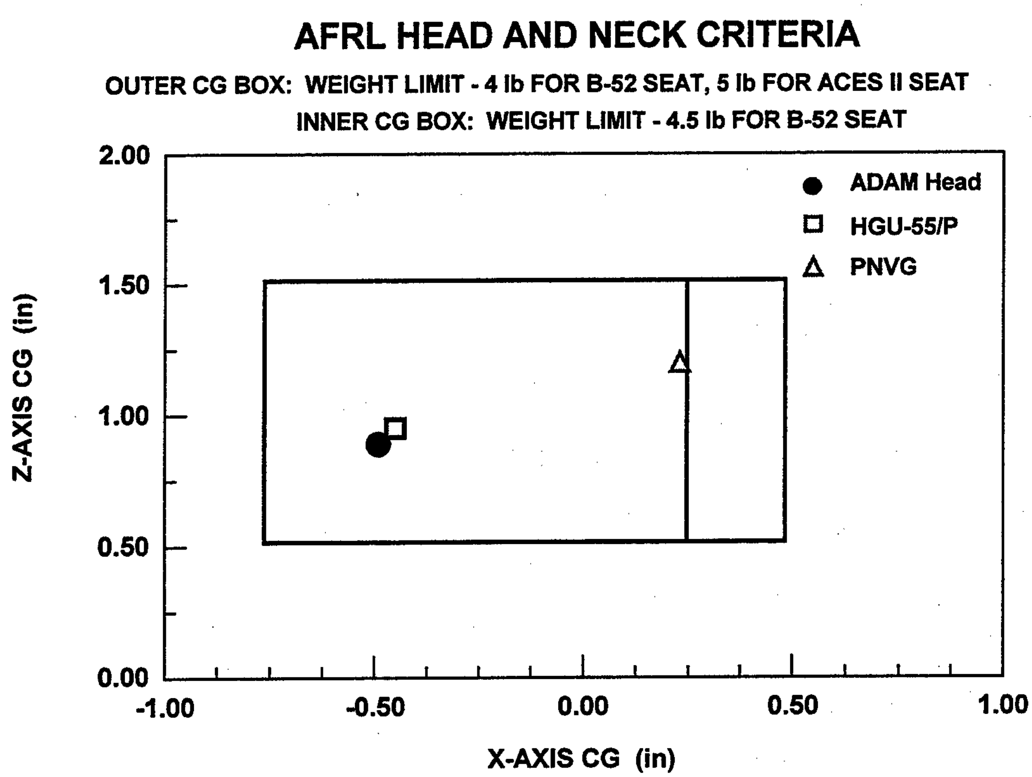

Figure 7. AFRL Head and Neck Helmet Inertial Property Criteria

Prior to statistical analysis of the measured acceleration and load data, an evaluation was completed on each set of data per helmet and per parameter to search for outliers. The evaluation test that was used is called Grubb's Test (Taylor, 1990). This test generates a range in which the data value can be expected to fall given a specific confidence level. The range is generated using the following equation:

$$G_R = \bar{x} \pm (s * T)$$

where G_R is the Grubb's Test data range, $\bar{x}$ is the data set mean, s is the data set standard deviation, the T is the Grubb's Test critical value which is a function of the sample size and the chosen confidence level. A total of six data outliers were found. One outlier was in the positive x-axis head acceleration data set for cell A, and the others were in the positive R_y head, negative head x-axis acceleration, negative head R_y acceleration, negative neck x-axis force, and negative shoulder x-axis load data sets in Cell B. R_y head acceleration is defined as the rotational acceleration of the head around its y-axis during flexion/extension head motion. These data points were removed from the analysis for the indicated parameter data sets.

Samples of the test results from the acceleration data are shown in Table 3. The data show that the PNVG helmet system induces slightly greater head accelerations during a 10 G impact compared to the HGU-55/P helmet. Linear acceleration in the z-axis, and R_y head rotational acceleration exhibited the greatest changes. These changes translated into the neck loads as well (refer to Table 4). The z-axis compressive neck load and the M_y rotational neck moment parameters exhibited the greatest differences between helmets, with the PNVG helmet system loads being larger than the baseline helmet. The PNVG did not appear to influence the x-axis shear load to any extent; however, it should be noted that the increased head rotation with the PNVG helmet induced some forward translation of the upper torso as indicated by the increased x-axis loads in the shoulder restraints.

Table 3. Peak Acceleration Data

Acceleration Parameter	**Cell A Baseline HGU-55/P Helmet**	**Cell B PNVG Helmet**
Carriage Z-Axis (G)	9.80 ± 0.07	9.79 ± 0.06
ADAM Chest Z-Axis (G)	14.72 ± 0.55	15.51 ± 0.22
ADAM Head Z-Axis (G)	13.87 ± 0.65	14.63 ± 0.18
(+) ADAM Head X-Axis (G)	2.45 ± 0.19	2.29 ± 0.15
(-) ADAM Head X-Axis (G)	-3.28 ± 0.15	-3.33 ± 0.46
(-) ADAM Head R_y (rad/sec^2)	-194.15 ± 16.37	-232.55 ± 11.30

Table 4. Peak Neck Load-Cell Data

Load Parameter	Cell A Baseline HGU-55/P Helmet	Cell B PNVG Helmet
(-) X-Axis Shoulder Load (lb)	-82.90 ± 13.74	-93.07 ± 22.65
(+) X-Axis Neck Load (lb)	27.60 ± 2.85	27.87 ± 2.89
(-) X-Axis Neck Load (lb)	-40.07 ± 2.58	-57.11 ± 1.38
Z-Axis Neck Load (lb)	165.44 ± 8.68	213.04 ± 3.07
M_y Neck Moment (in-lb)	130.17 ± 4.76	152.12 ± 13.89

Previous testing has shown the x-axis and z-axis loads measured by the ADAM manikin to be fairly representative of the loads that would be experienced by human subjects (Buhrman, Perry, 1994). The loads measured by ADAM with both helmets were less than the human subject tolerance loads previously defined (260 lb z-axis compressive load, 80 lb x-axis shear load). To properly evaluate the M_y moment, the measured manikin data must first be adjusted to predict what the human neck would experience at the occipital condyle. This adjustment is made using the following regression equation:

$$T_H = 699.2 + \left[\left(-355.5 * H_{WT}\right) + \left(44.3 * H_{WT}^{\ 2}\right)\right] + \left(1.796 * T_M\right)$$

where T_H is the predicted human M_y moment, H_{WT} is the helmet weight, and T_M is the M_y moment measured by the ADAM neck load cell (Perry, 1994). The regression equation was developed using the large database of vertical impact collected using the AFRL VDT. Table 5 shows the results of the prediction. The predicted human moment is less than the previously defined human subject tolerance level of 400 in-lb.

Table 5. Measured ADAM and Estimated Human M_y Force

Neck Type	HGU-55/P Helmet Moment (in-lb)	PNVG Helmet Moment (in-lb)
ADAM	130.17	152.12
Human	294.37	333.79

In addition to the evaluation of the dynamic acceleration and load data, the motion of the PNVG helmet and its structural integrity were evaluated after each test. The motion of the helmet was evaluated to determine the degree of slippage of the system on the ADAM head during the dynamic impact. Prior to each test, the browline of the PNVG helmet was positioned approximately 2 inches above the pupil position of the ADAM's eye. After the test, the relative position was checked. In three of the five tests, there was forward rotation of the helmet approximately 0.2 inch, which indicated a very good fit of the helmet to the headform. The other two tests had no relative helmet rotation. This relative displacement was confirmed with the SELSPOT data. Also after each test, the structrual integrity of the mounting system was checked for failures at all mounting points and suspected points of high stress. No structural failures were found.

CONCLUSION

The effects of inertial property differences of the PNVG helmet system as compared to a baseline HGU-55/P were evaluated and found not to generate loads in the cervical spine during vertical acceleration greater than those experienced by the human volunteer subjects on the VDT at Wright-Patterson AFB, OH. Dynamic evaluation of the PNVG helmet using 10 G vertical impacts indicated that the PNVG helmet would not induce neck loads greater than established human tolerance values. Therefore, there would be no increase in the risk of injury wearing the PNVG during the catapult phase of ejection with an ACES II seat, compared to the risk with a current operational helmet. Dynamic evaluation of the PNVG helmet also found no structural failures to the PNVG mounting points.

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APPENDIX A.

Test Configuration and Data Acquisition System

TEST CONFIGURATION AND
DATA ACQUISITION SYSTEM FOR THE
VERTICAL IMPACT TESTS OF THE
PANORAMIC NIGHT VISION GOGGLE

(PNVG Study)

Prepared under
Contract F3301-96-DJ001

March 1999

DynCorp
Human Effectiveness Division
Building 824, Area B
Wright-Patterson AFB, Ohio 45433

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INTRODUCTION

The DynCorp Armstrong Laboratory Division prepared this report for the Armstrong Laboratory Escape and Impact Branch (AL/CFBE) under Air Force Contract F3301-96-DJ001. It describes the test facility, seat fixture, restraint configuration, test subjects, test configurations, data acquisition, and the instrumentation procedures that were used in The Vertical Impact Tests of the Panoramic Night Vision Goggle (PNVG Study). Eleven tests were conducted between 28 Oct and 29 Oct 1998 on the Vertical Deceleration Tower Test facility.

1. TEST FACILITY

The AFRL/HEPA Vertical Deceleration Tower (Figure A-1) was used for all of the tests. The facility consists of a 60-foot vertical steel tower, which supports a guide rail system, an impact carriage supporting a plunger, a hydraulic deceleration device and a test control and safety system. The impact carriage can be raised to a maximum height of 39 feet prior to release. After release, the carriage free falls until the plunger, attached to the undercarriage, enters a water filled cylinder mounted at the base of the tower. The subject experiences a deceleration impulse as the plunger displaces water in the cylinder. The deceleration profile is determined by the free fall distance, the carriage and test specimen mass, the shape of the plunger and the size of the cylinder orifice. A rubber bumper is used to absorb the final impact as the carriage stops.

For these tests, plunger Number 102 was mounted under the carriage. Drop height varied depending on the test cell requirements, which ranged from 11′4″ to 12′2″.

2. SEAT FIXTURE

The VIP seat fixture (Figure A-2) was used for all of the tests. The seat was designed to withstand vertical impact accelerations up to 50 G. The seat pan and seat back are adjustable. For this study, the seat back and headrest were exactly vertical to be in line with the impact vector. The seat pan was perpendicular to the seat back. The subject was secured in the seat with a standard USAF double shoulder strap restraint harness and lap belt configuration. The lap belt and shoulder strap were preloaded to 20 ±5 pounds, as required in the test plan.

The manikins' hands were folded and positioned so they were resting on the lap and were loosely tied together with a Velcro strap. The manikin was centered in the seat sitting straight up with the lower back pressed against the seat back.

3. TEST SUBJECT

One manikin was used for this test program: a large Advanced Dynamic Anthropomorphic Manikin (ADAM) weighing 218 pounds. Figure A- 3 shows the manikin in the VIP seat, and Figure A- 4 is a close up of the Panoramic Night Vision Goggles.

4. TEST CONFIGURATIONS

The detailed test configurations are outlined below:

Test Cell	Impact Level	No. Impacts	O_2 Mask	Helmet
A	10 G	5	MBU-12/P	HGU-55/P
B	10 G	5	MBU-20/P	PNVG

Table A - 1: Test Matrix

5. INSTRUMENTATION

Accelerometers and load transducers were chosen to provide the optimum resolution over the expected test load range. Full scale data ranges were chosen to provide the expected full scale range plus 50% to assure the capture of peak signals. All transducer bridges were balanced for optimum output prior to the start of the program. The accelerometers were adjusted for the effect of gravity in software by adding the component of a 1 G vector in line with the force of gravity that lies along the accelerometer axis.

The accelerometer and load transducer coordinate systems are shown in Figure A-5. The seat coordinate system is right-handed with the z-axis parallel to the seat back and positive upward. The x-axis is perpendicular to the z-axis and positive eyes forward from the subject. The y-axis is perpendicular to the x and z-axes according to the right-hand rule. The origin of the seat coordinate system is designated as the seat reference point (SRP). The SRP is at the midpoint of the line segment formed by the intersection of the seat pan and seat back. All vector components (for accelerations, angular accelerations, forces, moments, etc.) were positive when the vector component (x, y and z) was in the direction of the positive axis.

The linear accelerometers were wired to provide a positive output voltage when the acceleration experienced by the accelerometer was applied in the +x, +y and +z directions. The load cells and load links were wired to provide a positive output voltage when the force exerted by the load cell on the subject was applied in the +x, +y or +z direction. All transducers, except the carriage accelerometers and the carriage velocity tachometer, were referenced to the seat coordinate system. The carriage tachometer was wired to provide a positive output voltage during freefall. The carriage accelerometers were referenced to the carriage coordinate system. The measurement instrumentation used in this test program is listed in Table A-2.

Carriage velocity was measured using a Globe Industries tachometer (Model 22A672-2). The rotor of the tachometer was attached to an aluminum wheel with a rubber "O" ring around its circumference to assure good rail contact. The wheel contacted the track rail and rotated as the carriage moved, producing an output voltage proportional to the velocity.

5.1 Accelerometers

Internal accelerometer packages were mounted in the manikin chest and head. They were arranged to measure linear acceleration of the chest and head in all three axes, and angular acceleration of the head about all three axes. The specific transducers used are listed by channel in Table A- 2, the Setup and Calibration Log.

Carriage z acceleration was measured using one Endevco Model 2262A-200 linear accelerometer. The accelerometer was mounted on a small acrylic block and located behind the seat on the VIP seat structure. Additional linear accelerometers were used to measure acceleration at the seat pan. They were attached to a 1 x 1 x ¾-inch acrylic block and were mounted near the center of the load cell mounting plate. Specific sensors are listed by channel in Table A- 2.

5.2 Load Transducers

Shoulder/anchor forces were measured using a mix of available load cells. Specific sensors are listed by channel in Table A-2. The load parameters measured are indicated below:

Shoulder x, y and z force
Seat Pan x, y, and z force
Head Rest x force
Left lap belt x, y and z force
Right lap belt x, y and z force.

The lap/vertical anchor force triaxial load cells were located on separate brackets mounted on the side of the seat frame parallel to the seat pan. The shoulder strap force triaxial load cell was mounted on the seat frame between the seat back support plate and the headrest. The load transducer locations are shown in Figure A-5.

Left, right and center seat forces were measured using three load cells and three load links. The three load cells included three Strainsert Model FL2.5U-2SPKT load cells. DynCorp fabricated the three load links (Figure A-6) using Micro Measurement Model EA-06-062TJ-350 strain gages. All measurement devices were located under the seat pan support plate. The load links were used for measuring loads in the x and y directions, two in the x direction and one in the y direction. Each load link housed a swivel ball, which acted as a coupler between the seat pan and load cell mounting plate. The Strainsert load cells were used for measuring loads in the z direction.

5.3 Calibration

Calibrations were performed before and after testing to confirm the accuracy and functional characteristics of the transducers. Pre-program and post-program calibrations are given in Table A-3. The Precision Measurement Equipment Laboratories (PMEL) at Wright-Patterson Air Force Base calibrated all Strainsert load cells. PMEL calibrated these devices on a periodic basis and provided current sensitivity and linearity data.

The calibration of the accelerometers was performed by DynCorp using the comparison method (Ensor, 1970). A laboratory standard accelerometer, calibrated on a yearly basis by Endevco with standards traceable to the National Bureau of Standards, and a test accelerometer were mounted on a shaker table. The frequency response and phase shift of the test accelerometer were determined by driving the shaker table with a random noise generator and analyzing the

outputs of the accelerometers with an MS-DOS PC computer using Fourier analysis. The natural frequency and the damping factor of the test accelerometer were determined, recorded and compared to previous calibration data for that test accelerometer. Sensitivities were calculated at 40 G and 100 Hertz. The sensitivity of the test accelerometer was determined by comparing its output to the output of the standard accelerometer.

DynCorp calibrated the shoulder/lap triaxial load cells and load links. These transducers were calibrated to a laboratory standard load cell in a special test fixture. The sensitivity and linearity of each test load cell were obtained by comparing the output of the test load cell to the output of the laboratory standard under identical loading conditions. The laboratory standard load cell, in turn, is calibrated by PMEL on a periodic basis.

The angular accelerometers are calibrated on a periodic basis by comparing their output to the output of a linear standard accelerometer. The angular sensors are mounted parallel to the axis of rotation of a Honeywell low inertia D.C. motor. The linear sensor is mounted perpendicular to the axis of rotation. An alternating current is supplied to the motor, which drives a constant sinusoidal angular acceleration of 100 Hertz. The sensitivity of the angular accelerometer is calculated from the RMS output voltage to match the angular value computed from the linear standard.

The velocity wheel is calibrated periodically by DynCorp by rotating the wheel at approximately 2000, 4000 and 6000 revolutions per minute (RPM) and recording both the output voltage and the RPM.

6. DATA ACQUISITION

The Master Instrumentation Control Unit in the Instrumentation Station controls data acquisition. Using a comparator, a test was initiated when the countdown clock reaches zero. The comparator is set to start data collection at a pre-selected time. All data was collected at 1000 samples per second and filtered at 120 Hz cutoff frequency using a 8-pole Butterworth filter.

Prior to placing a subject in the seat, data was recorded to establish a zero reference for all transducers. The reference data was stored separately from the test data and was used in the processing of the test data. A reference mark pulse was generated to mark the Model 5600A electronic data and Selspot optical motion data at a pre-selected time after test initiation to place the reference mark close to the impact point. The reference mark time was used as the start time for data processing of the electronic and Selspot optical motion data.

6.1 Model 5600 Portable Data Acquisition System

The Model 5600A Portable Data Acquisition System (DAS), manufactured by Pacific Instruments, was used for this test program. The Model 5600A DAS is a ruggedized, DC powered, fully programmable signal conditioning and recording system for transducers and events. The Model 5600A DAS is designed to withstand a 50G shock in any direction. The Model 5600A DAS is housed in two units and its installation on top of the seat carriage is shown in Figure A-7.

Each of the two units can accommodate up to 28 transducer channels and 32 events. The signal conditioning accepts a variety of transducers including full and partial bridges, voltage, and piezoresistive. Transducer signals are amplified, filtered, digitized and recorded in onboard solid state memory. The data acquisition system is controlled through an IEEE-488.1 interface using the GPIB instruction language.

An MS-DOS PC with an AT-GPIB board configures the 5600A before testing and retrieves the data after each test. The PC stores the raw data and then passes it on to a DEC Alpha computer for processing and output to permanent storage and printouts.

The DynCorp program 'TDR5600' on the PC handles the interface with the Model 5600A DAS. It includes options to compute and store zero reference voltage values; collect and store a binary zero reference data file; compute and display preload values; and collect and store binary test data. The program communicates over the GPIB interface.

Test data could be reviewed after it was converted to digital format using the "quick look" SCAN_EME routine on the DEC Alpha computer. SCAN_EME produced a plot of the data stored for each channel as a function of time. The routine determined the minimum and maximum values of each data plot. It also calculated the rise time, pulse duration, and carriage acceleration, and created a disk file containing significant test parameters.

6.2 Selspot Motion Analysis System

The Selspot Motion Analysis System utilizes photosensitive cameras to track the motion of infrared LED targets attached to different points on the test fixture. The three-dimensional motion of the LEDs was determined by combining the images from two different Selspot cameras. The two Selspot cameras were mounted onboard the carriage. The side camera was a Selspot Model 412 (S/N

457) and the oblique camera was a Selspot Model 412 (S/N 458). Both cameras had 24mm lenses. A Motorola 68030 VME based microcomputer in the camera interface unit handles camera control and photogrammetric data collection. An MS DOS PC, running Selspot MULTILAB System software, is used to trigger the Selspot system, process the data, generate printouts, and temporarily store the data. Figure A- 8 shows a block diagram of the SELSPOT architecture.

The Selspot System was calibrated by determining the camera locations and orientations prior to the start of the test program. The camera locations and orientations were referenced to the coordinate system of the Position Reference Structure (PRS). The PRS is shaped as a tetrahedron with reference LEDs 1, 2, 3 and 4 located at the vertices. The PRS is shown in Figure A-9.

Motion of the subjects' helmet, head, shoulder, and chest were quantified by tracking the motion of subject-mounted LEDs. Four reference LEDs were placed on the test fixture. The locations of the LEDs generally followed the guidelines provided in "Film Analysis Guides for Dynamic Studies of Test Subjects, Recommended Practice (SAE J138, March 1980)." Figure A-10 identifies the LED target locations.

Photogrammetric data was collected from the six moving and four reference LEDs at a 500 Hz sample rate during the impact. Data collection started at T = -3 seconds for 5 seconds. The data was processed starting at the reference mark time for 600 milliseconds on the Selspot Motion Analysis System. The camera image coordinates were corrected for camera vibration, converted into three-dimensional coordinates, and transformed into the seat coordinate seat.

A Kodak Ektapro 1000 video system was also used to provide onboard coverage of each test. This video recorder and display unit is capable of recording high-speed motion up to a rate of 1000 frames per second. Immediate replay of the impact is possible in real time or in slow motion.

7. PROCESSING PROGRAMS

The Excel 97 Workbook PnvgVdt.xls is used to analyze the TDR5600 DAS test data from the PNVG Study (Vertical Deceleration Tower Facility). PnvgVdt.xls contains the Visual Basic module Module1 and the forms UserForm1 and UserForm2. Module1 contains one main subroutine that calls numerous other subroutines and functions. PnvgVdt.xls calls the DLL functions in the Dynamic Link Libraries Scandll and Mathdll. The shortcut ctrl+r can be used to execute the Visual Basic module. The Visual Basic module displays the two user forms.

UserForm1 requests the user to enter the system acronym, study description,

DYNCORP

PROGRAM: Verticle Impact Tests of the Panoramic Night Vision Goggle

FACILITY: Verticle Drop Tower

DATA COLLECTION SYSTEM: Pacific Instruments

TEST DATES: 28 OCT - 29 OCT 1998
TEST NUMBERS: 3884 - 3894
SAMPLE RATE: 1K
FILTER FREQUENCY: 120 Hz
TRANSDUCER RANGE (VOLTS): +/- 10

DATA CHANNEL	DATA POINT	TRANSDUCER MFG. & MODEL	SERIAL NUMBER	PRE-CAL		POST-CAL		% Δ	EXC. VOL.	AMP GAIN	FULL SCALE	NOTES
				DATE	SENS	DATE	SENS					
0	VELOCITY	GLOBE 22A672-2	4	13-Nov-96	.158 v/ft/sec				10	1	63.3 FT/SEC	Raw Sensitivity = .1857 v/rev/sec; (12in/ft/4.56 in/rev)x .1857 v/r/s = .4887 rev/ft; Atten @ 3.094; .4887v/ft(1/3.094) = .158 v/ft/sec
1	CARRIAGE X ACCEL (G)	ENTRAN EGE-72B-200	95H95H14-A04	7-Aug-98	2.6739 mv/g	4-Nov-98	2.6725 mv/g	-.1	10	100	37.4 G	
2	CARRIAGE Y ACCEL (G)	ENTRAN EGE-72B-200	95H95H14-A05	10-Aug-98	2.8535 mv/g	4-Nov-98	2.8478 mv/g	-.2	10	100	35.0 G	
3	CARRIAGE Z ACCEL (G)	ENDEVCO 2262A-200	MH82	24-Feb-98	2.0602 mv/g				10	100	48.5 G	Replaced by 95H95H14-A07 on test 3885. Cable shorted out on test 3884.
3	CARRIAGE Z ACCEL (G)	ENTRAN EGE-72B-200	95H95H14-A07	9-Sep-97	2.5784 mv/g	4-Nov-98	2.5876 mv/g	.4	10	100	38.8 G	Replaced MH82 on test 3885. Cable shorted out on test 3884.
4	SEAT PAN X ACCEL (G)	ENTRAN EGE-72B-200	95C95C10-G01	10-Aug-98	2.7205 mv/g	4-Nov-98	2.7163 mv/g	-.2	10	200	18.4 G	
5	SEAT PAN Y ACCEL (G)	ENTRAN EGE-72B-200	95C95C10-G02	10-Aug-98	2.7361 mv/g	4-Nov-98	2.7389 mv/g	.1	10	200	18.3 G	

Program Setup and Calibration Log

Sheet 1 of 5

DYNCORP

DATA CHANNEL	DATA POINT	TRANSDUCER MFG. & MODEL	SERIAL NUMBER	PRE-CAL DATE	PRE-CAL SENS	POST-CAL DATE	POST-CAL SENS	% Δ	EXC. VOL.	AMP GAIN	FULL SCALE	NOTES
6	SEAT PAN Z ACCEL (G)	ENTRAN EGE-72B-200	95C95C10-G03	10-Feb-98	2.5098 mv/g	4-Nov-98	2.5070 mv/g	-.1	10	100	39.8 G	
7	INT HEAD X ACCEL (G)	ENDEVCO 7264-200	BH76H	23-Feb-98	3.1363 mv/g	4-Nov-98	3.1872 mv/g	1.6	10	100	31.9 G	
8	INT HEAD Y ACCEL (G)	ENDEVCO 7264-200	CA53H	23-Feb-98	-2.6527 mv/g	4-Nov-98	2.6640 mv/g	.4	10	100	37.7 G	Use Negative Sensitivity
9	INT HEAD Z ACCEL (G)	ENDEVCO 7264-200	CD85H	23-Feb-98	2.6781 mv/g	4-Nov-98	2.6498 mv/g	-1.1	10	50	74.7 G	
10	INT HEAD RY ANG ACCEL (RAD/SEC2)	ENDEVCO 7302B	F93M	10-Aug-98	-3.67 uv/rad/sec2	4-Nov-98	3.74 mv/g	1.9	10	500	5449.6 RAD/SEC2	Use Negative Sensitivity
11	INT CHEST X ACCEL (G)	ENTRAN EGE-72B-200	93C93C19-R14	10-Aug-98	2.3048 mv/g	4-Nov-98	2.2949 mv/g	-.4	10	100	43.4 G	
12	INT CHEST Y ACCEL (G)	ENDEVCO 7264-200	CL86H	23-Feb-98	-2.8803 mv/g	4-Nov-98	2.8930 mv/g	.4	10	100	34.7 G	Use Negative Sensitivity
13	INT CHEST Z ACCEL (G)	ENTRAN EGE-72B-200	95I95I06-D02	9-Sep-97	2.6710 mv/g	4-Nov-98	2.6824 mv/g	.4	10	50	74.9 G	
14	INT NECK X FORCE (LB)	DENTON 1716A	820	11-Aug-98	-8.01 uv/lb	4-Nov-98	8.07 uv/lb	-1	10	1000	1248.4 LB	Switched to channel 38 for power distribution on test 3884. Use negative sensitivity.
15	INT NECK Y FORCE (LB)	DENTON 1716A	820	11-Aug-98	8.16 uv/lb	4-Nov-98	8.35 uv/lb	2.3	10	1000	1225.5 LB	Switched to channel 39 for power distribution on test 3884.

Program Setup and Calibration Log

DYNCORP

DATA CHANNEL	DATA POINT	TRANSDUCER MFG. & MODEL	SERIAL NUMBER	PRE-CAL		POST-CAL		% Δ	EXC. VOL.	AMP GAIN	FULL SCALE	NOTES
				DATE	SENS	DATE	SENS					
16	INT NECK Z FORCE (LB)	DENTON 1716A	820	11-Aug-98	-4.59 uv/lb	4-Nov-98	4.48 uv/lb	-2.4	10	1000	2178.6 LB	Switched to channel 45 for power distribution on test 3884. Use negative sensitivity.
17	INT NECK MX TORQUE (IN-LB)	DENTON 1716A	820	11-Aug-98	6.7 uv/lb	4-Nov-98	6.72 uv/lb	.3	10	500	2985.1 LB	Switched to channel 41for power distribution on test 3884.
18	INT NECK MY TORQUE (IN-LB)	DENTON 1716A	820	11-Aug-98	6.7 uv/lb	4-Nov-98	6.77 uv/lb	1	10	200	7462.7 LB	Switched to channel 42 for power distribution on test 3884.
19	INT NECK MZ TORQUE (IN-LB)	DENTON 1716A	820	11-Aug-98	9.13 uv/lb	4-Nov-98	9.13 uv/lb	0	10	500	2190.6 LB	Switched to channel 43 for power distribution on test 3884.
20	LEFT SEAT PAN Z FORCE (LB)	STRAINSERT FL2.5U-2SGKT	Q-7588-3	21-Jan-98	-7.82 mv/lb	NA	NA		10	500	2557.5 LB	Use Negative Sensitivity
21	RIGHT SEAT PAN Z FORCE (LB)	STRAINSERT FL2.5U-2SPKT	Q-3294-5	21-Jan-98	-7.6 uv/lb	NA	NA		10	500	2631.6 LB	Use Negative Sensitivity
22	CENTER SEAT PAN Z FORCE (LB)	STRAINSERT FL2.5U-2SPKT	Q-3294-6	21-Jan-98	-7.65 uv/lb	NA	NA		10	200	6535.9 LB	Use Negative Sensitivity
23	LEFT SEAT PAN X FORCE (LB)	AAMRL / DYN LINK	1	18-Aug-98	11.77 uv/lb	4-Nov-98	11.44 uv/lb	-2.8	10	1000	849.6 LB	
24	RIGHT SEAT PAN X FORCE (LB)	AAMRL / DYN LINK	2	18-Aug-98	-11.4 uv/lb	4-Nov-98	11.25 uv/lb	-1.3	10	1000	877.2 LB	Use Negative Sensitivity
25	SEAT PAN Y FORCE (LB)	AAMRL / DYN LINK	3A	18-Aug-98	11.04 uv/lb	4-Nov-98	10.9 uv/lb	-1.3	10	1000	905.8 LB	

Program Setup and Calibration Log **Sheet 3 of 5**

DYNCORP

DATA CHANNEL	DATA POINT	TRANSDUCER MFG. & MODEL	SERIAL NUMBER	PRE-CAL		POST-CAL		% Δ	EXC. VOL.	AMP GAIN	FULL SCALE	NOTES
				DATE	SENS	DATE	SENS					
26	LEFT LAP X FORCE (LB)	MICHIGAN SCIENTIFIC 4000	4	22-Dec-97	13.28 uv/lb	5-Nov-98	13.7 uv/lb	3.3	10	500	1506 LB	Switched to channel 29 due to channel being bad.
27	LEFT LAP Y FORCE (LB)	MICHIGAN SCIENTIFIC 4000	4	22-Dec-97	-13.52 uv/lb	5-Nov-98	14.01 uv/lb	3.6	10	500	1479.3 LB	Use Negative Sensitivity
28	EVENT / T=0								0	1		BIT 0 is EVENT BIT 1 is T=0
29	LEFT LAP Z FORCE (LB)	MICHIGAN SCIENTIFIC 4000	4	22-Dec-98	13.27 uv/Lb	5-Nov-98	13.7 uv/lb	3.2	10	500	1507.2 LB	Switched to channel 46 on test 3884 due to bad channel.
30	RIGHT LAP X FORCE (LB)	MICHIGAN SCIENTIFIC 4000	5	22-Dec-97	-13.38 uv/lb	5-Nov-98	13.95 uv/lb	4.3	10	500	1494.8 LB	Use Negative Sensitivity
31	RIGHT LAP Y FORCE (LB)	MICHIGAN SCIENTIFIC 4000	5	22-Dec-97	14.13 uv/lb	5-Nov-98	14.62 uv/lb	3.5	10	500	1415.4 LB	
32	RIGHT LAP Z FORCE (LB)	MICHIGAN SCIENTIFIC 4000	5	22-Dec-97	13.26 uv/lb	5-Nov-98	13.54 uv/lb	2.1	10	500	1508.3 LB	
33	SHOULDER X FORCE (LB)	GM 3D-SW	23	12-Aug-98	7.37 uv/lb	4-Nov-98	7.33 uv/lb	-.5	10	1000	1356.9 LB	
34	SHOULDER Y FORCE (LB)	GM 3D-SW	23	12-Aug-98	7.62 uv/lb	4-Nov-98	7.65 uv/lb	-.4	10	1000	1312.3 LB	
35	SHOULDER Z FORCE (LB)	GM 3D-SW	23	12-Aug-98	8.30 uv/lb	4-Nov-98	8.21 uv/lb	-1.1	10	500	2409.6 LB	

Program Setup and Calibration Log

Sheet 4 of 5

DYNCORP

DATA CHANNEL	DATA POINT	TRANSDUCER MFG. & MODEL	SERIAL NUMBER	PRE-CAL		POST-CAL		% Δ	EXC. VOL.	AMP GAIN	FULL SCALE	NOTES
				DATE	SENS	DATE	SENS					
36	UPPER HEADREST X FORCE (LB)	STRAINSERT FL1U-2SGKT	Q-3008-1	23-Feb-98	-9.94 uv/lb	NA	NA		10	1000	1006 LB	Use Negative Sensitivity
37	LOWER HEADREST X FORCE (LB)	STRAINSERT FL1U-2SGKT	Q-3008-2	23-Feb-98	-9.98 uv/lb	NA	NA		10	1000	1002 LB	Switched to channel 44 due to bad channel. Use negative sensitivity.

Program Setup and Calibration Log

Sheet 5 of 5

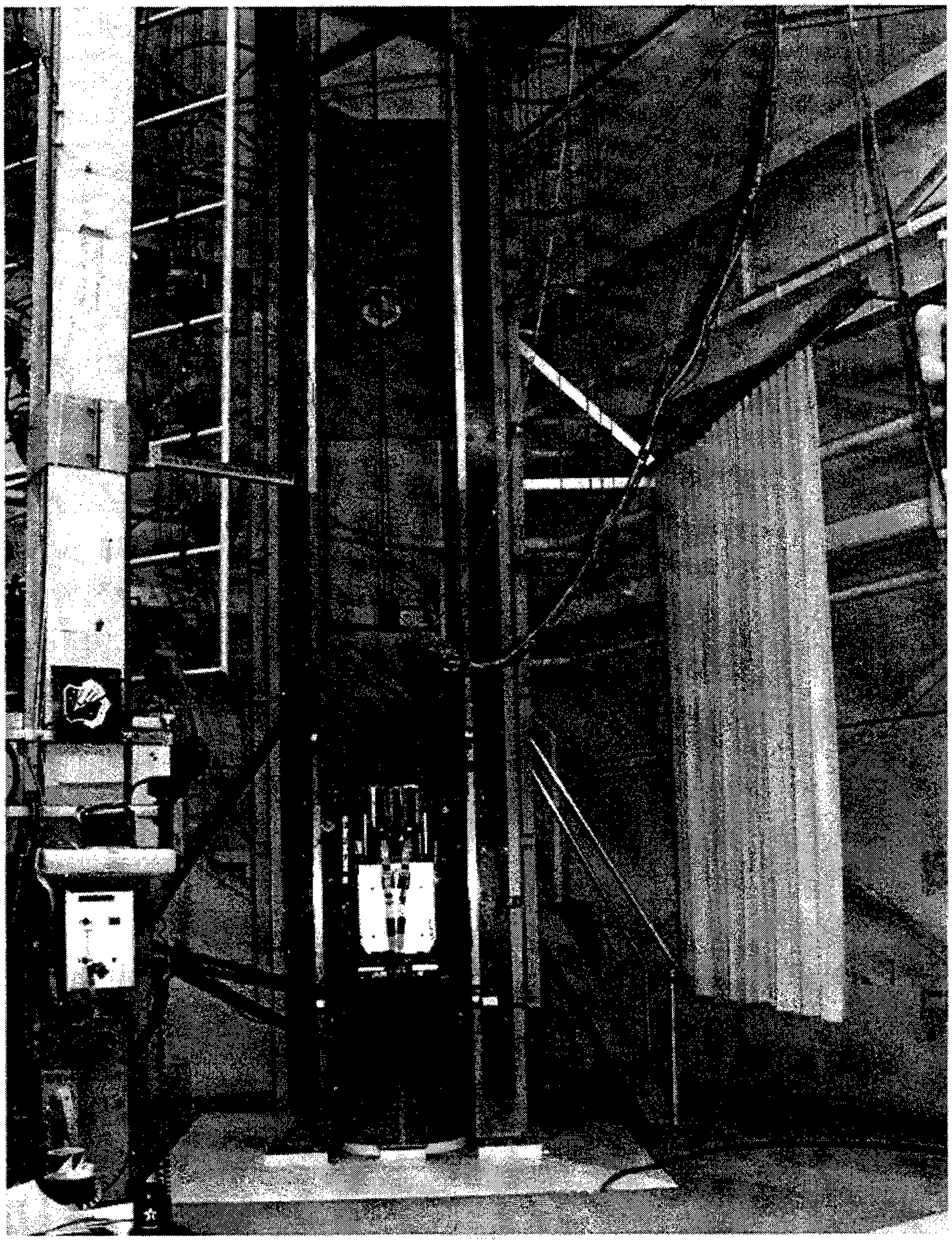


Figure A- 1: AL/CFBE Vertical Deceleration Tower

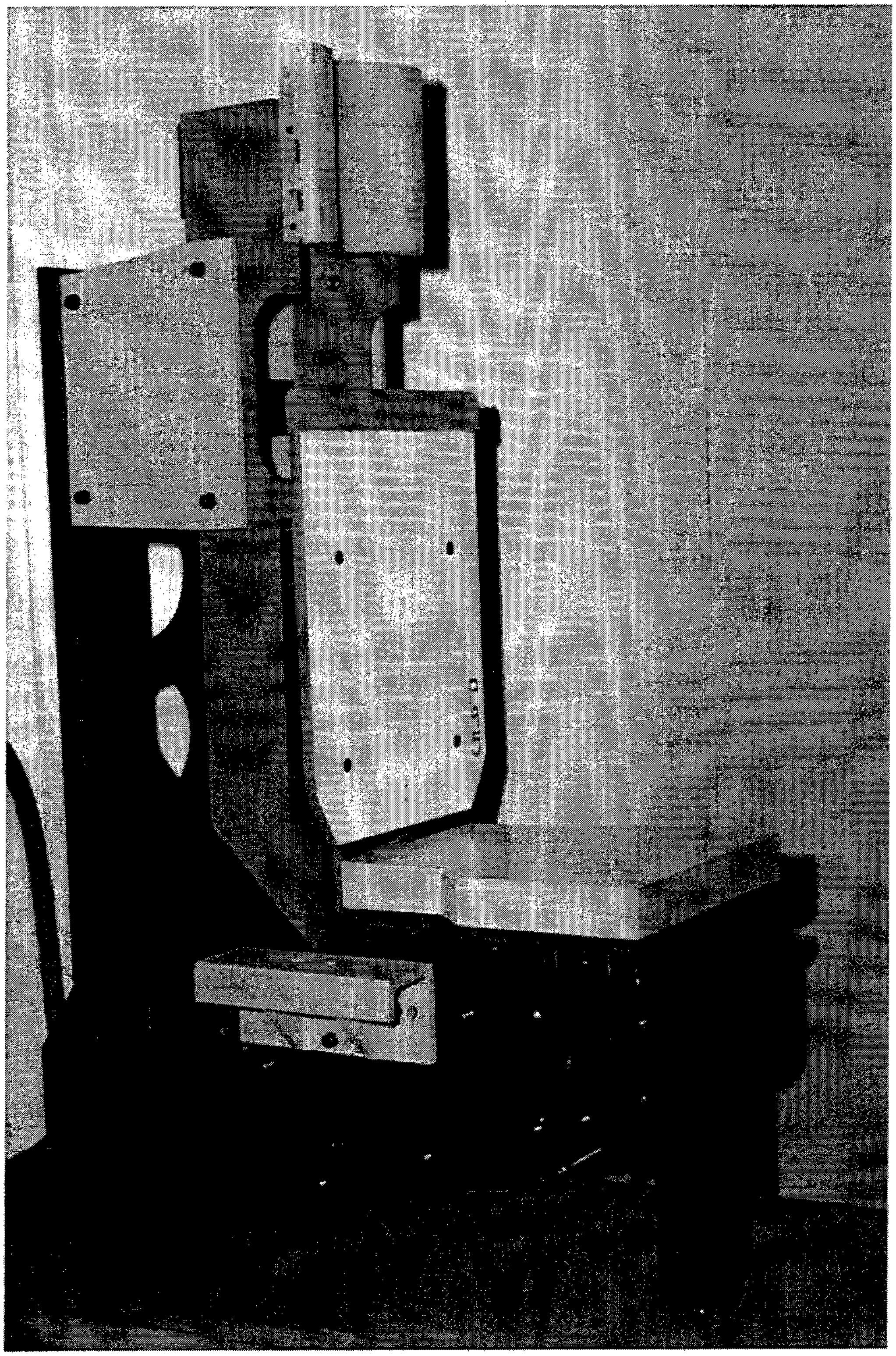


Figure A- 2: Basic VIP Seat

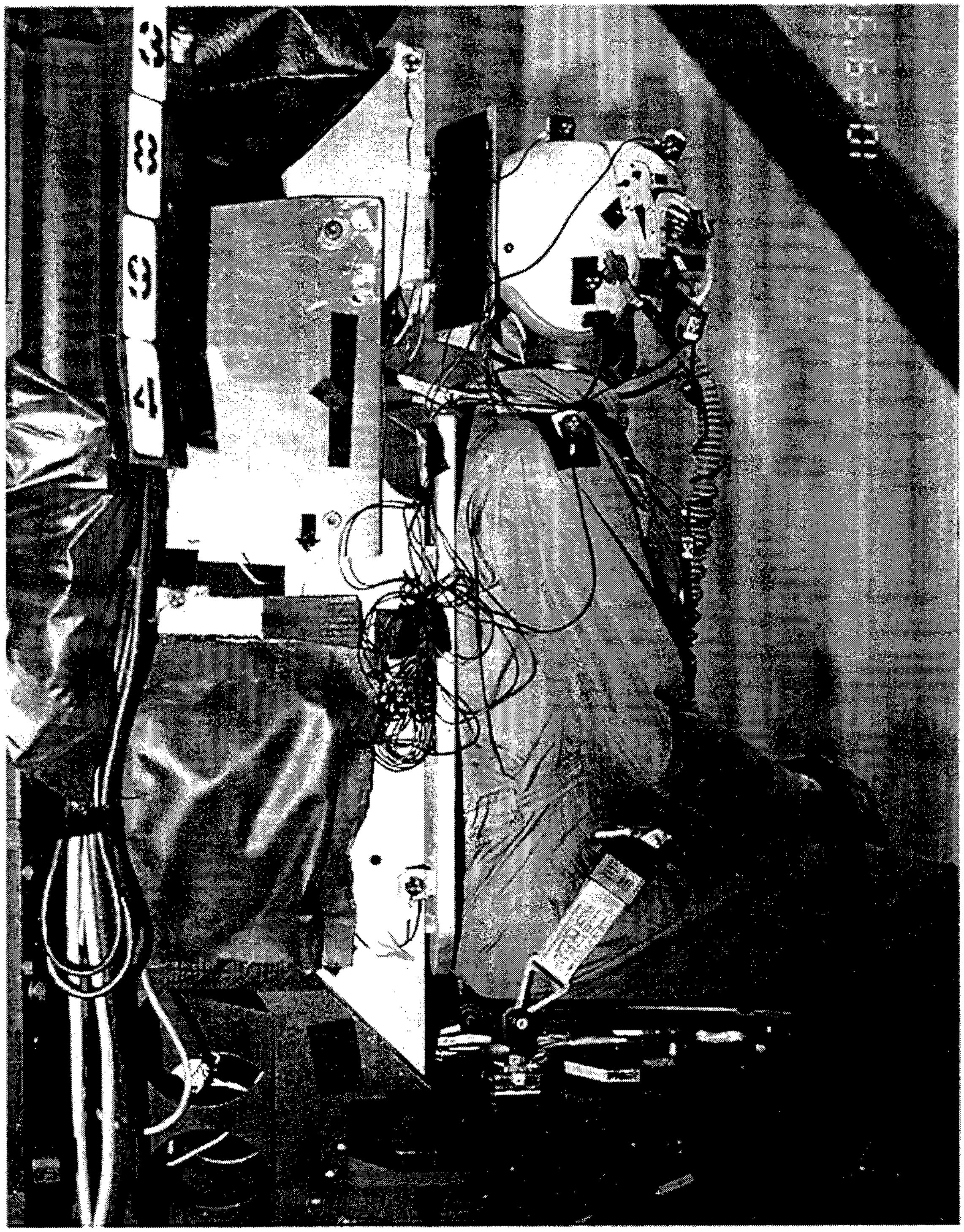


Figure A- 3: Test Setup Detail, Side View

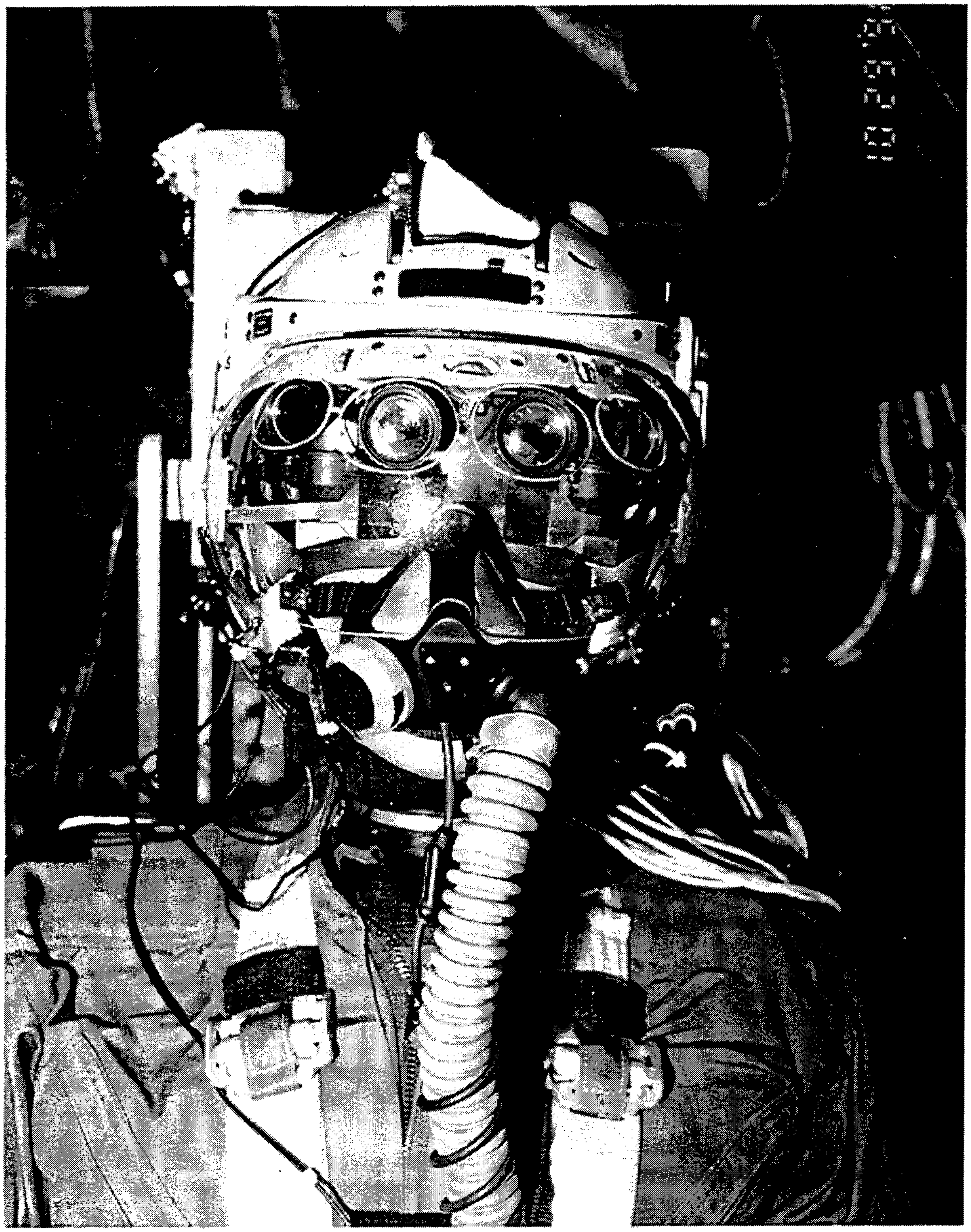
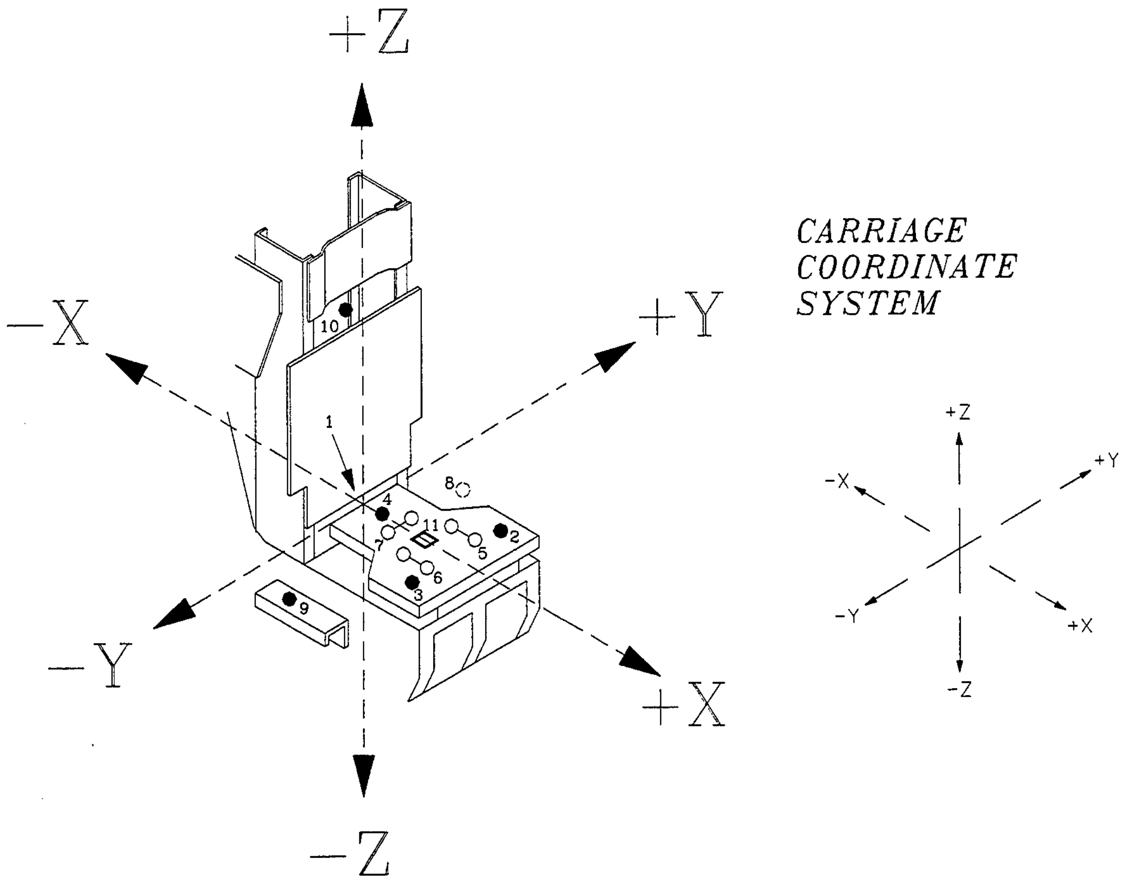


Figure A- 4: Night Vision Goggle, Closeup

A - 19



TRANSDUCER CONTACT POINT LOCATIONS IN INCHES (CM)

NO.	X	Y	Z	DESCRIPTION
1	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	SEAT REFERENCE POINT
2	17.90 (45.46)	5.00 (12.70)	-1.22 (-3.10)	LEFT SEAT Z FORCE
3	17.90 (45.46)	-5.00 (-12.70)	-1.22 (-3.10)	RIGHT SEAT Z FORCE
4	6.68 (16.96)	0.00 (0.00)	-1.22 (-3.10)	CENTER SEAT Z FORCE
5	10.00 (25.41)	6.00 (15.25)	-1.85 (-4.70)	LEFT SEAT X FORCE
6	10.00 (25.41)	-6.00 (-15.25)	-1.85 (- 4.70)	RIGHT SEAT X FORCE
7	9.26 (23.51)	1.99 (5.05)	-1.85 (-4.70)	CENTER SEAT Y FORCE
8	0.81 (2.06)	9.00 (22.86)	-1.61 (-4.10)	LEFT LAP BELT FORCE
9	0.81 (2.06)	-9.00 (-22.86)	-1.61 (-4.10)	RIGHT LAP BELT FORCE
10	-5.47 (-13.90)	0.00 (0.00)	27.39 (69.58)	SHOULDER FORCE
11	12.33 (31.31)	0.00 (0.00)	-1.69 (-4.30)	X, Y, Z ACCELERATION

Figure A- 5: VDT Coordinate System

A - 20

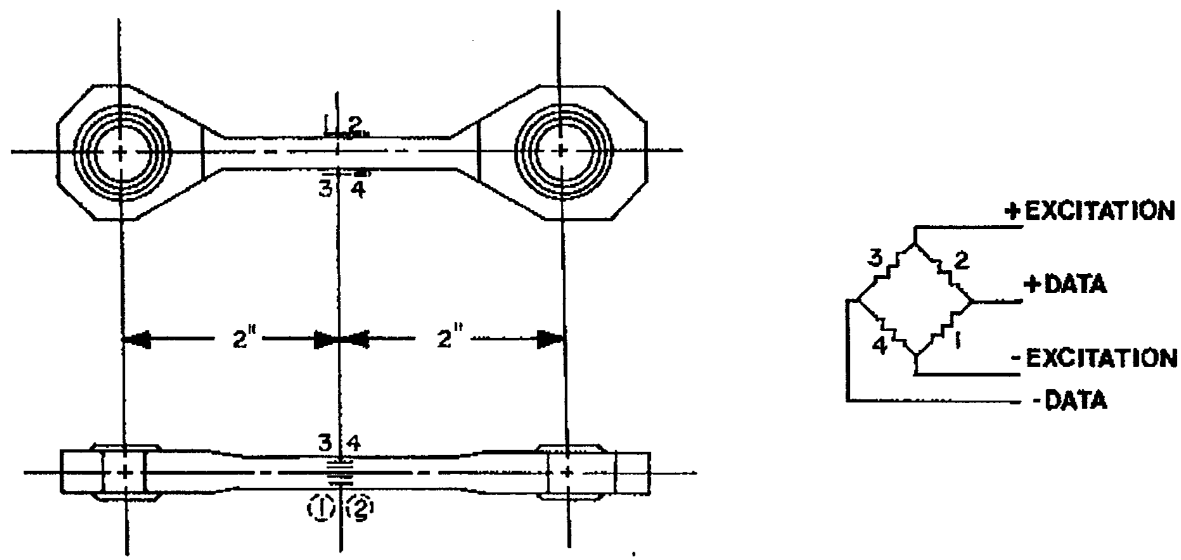


Figure A- 6: Load Link Instrumentation

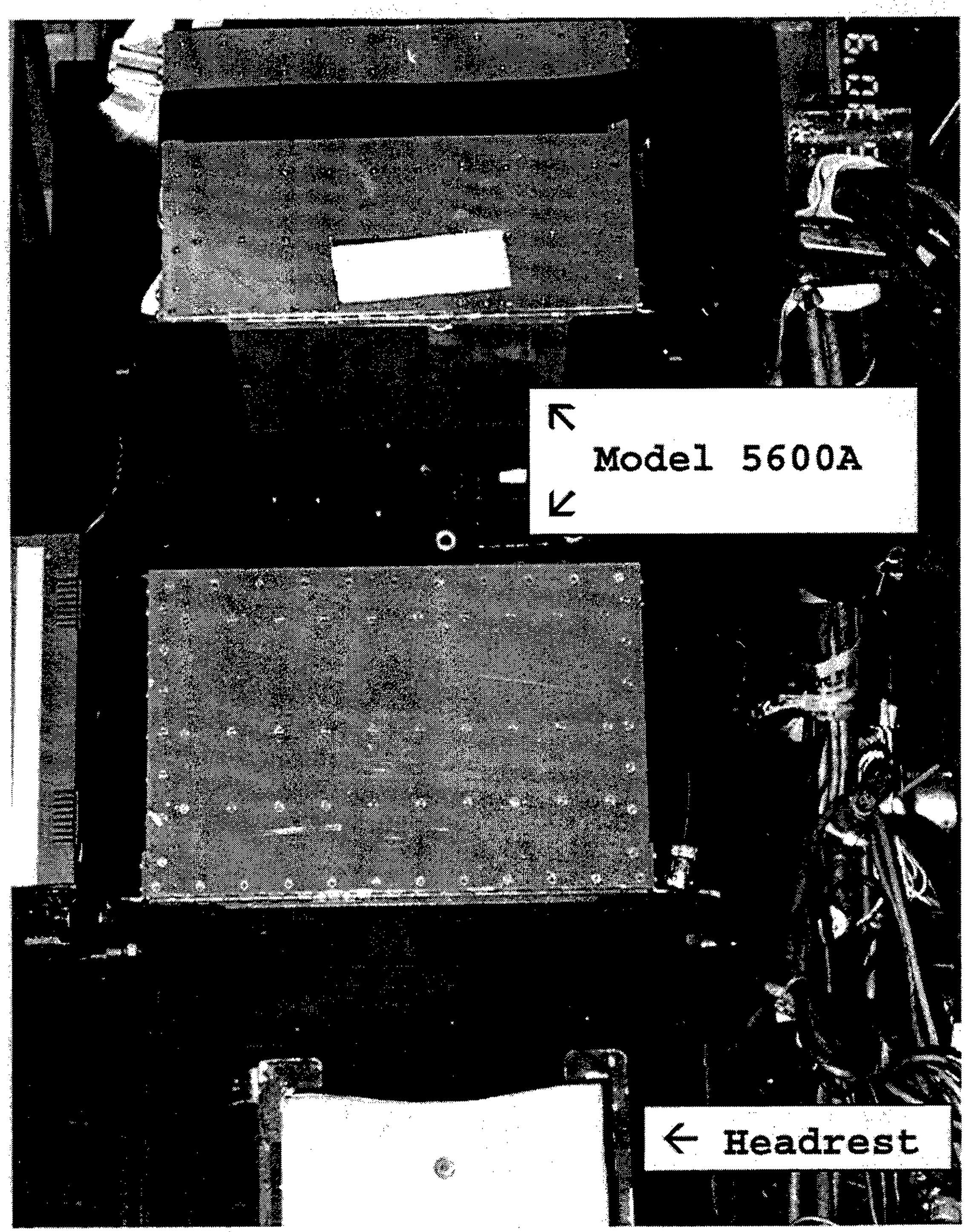


Figure A- 7: Pacific Instruments Model 5600A DAS

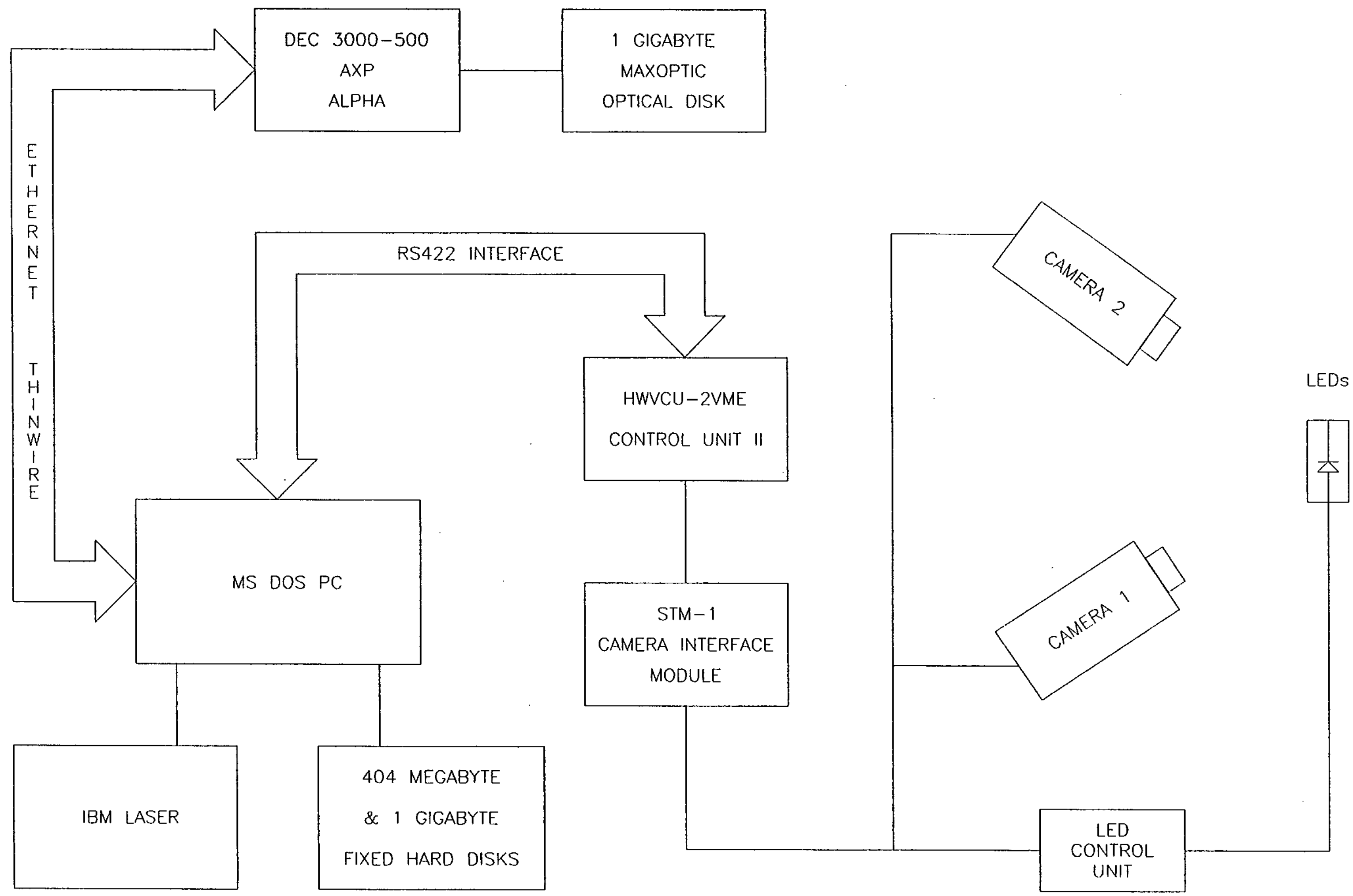


Figure A- 8: Selspot Data Acquisition Block Diagram

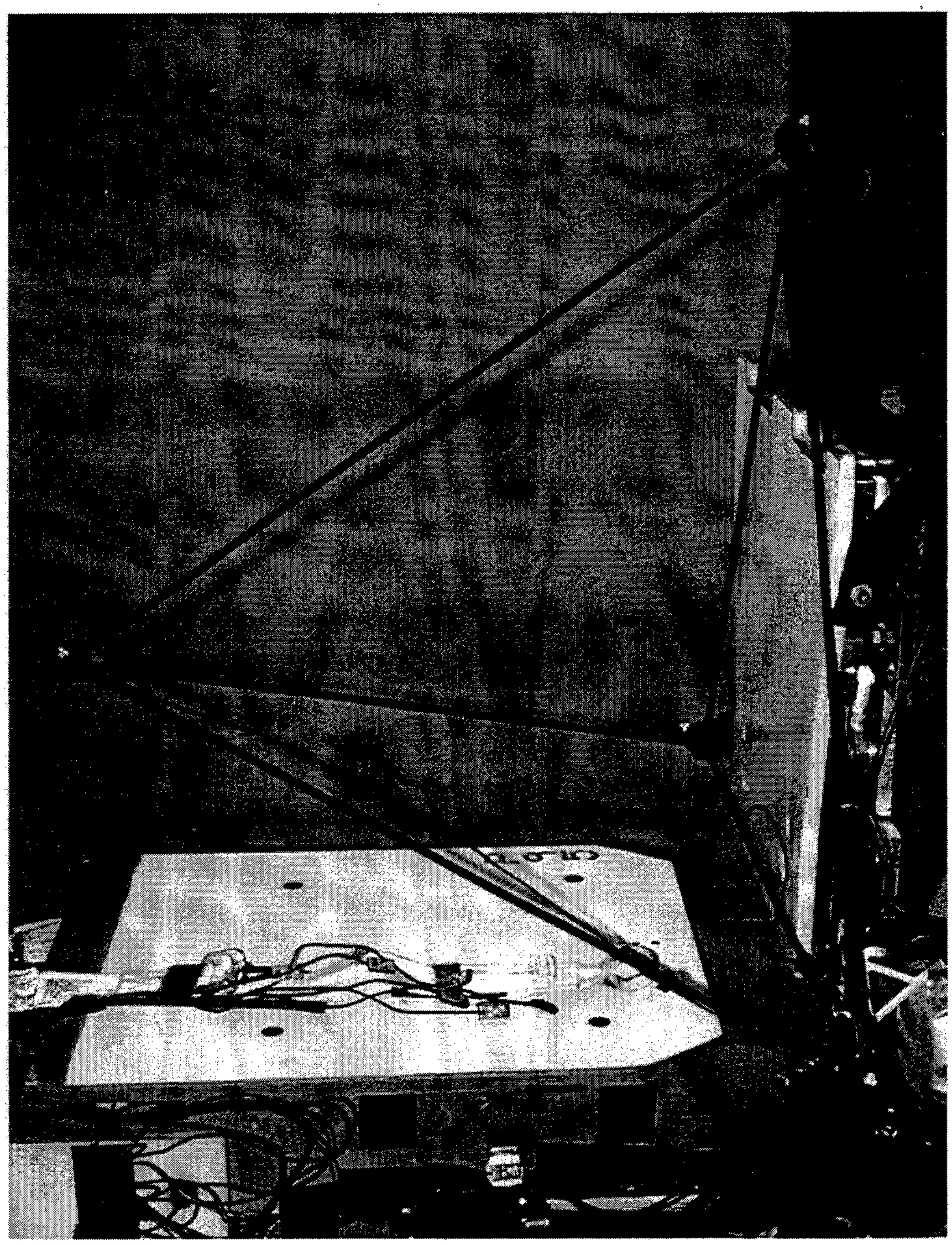
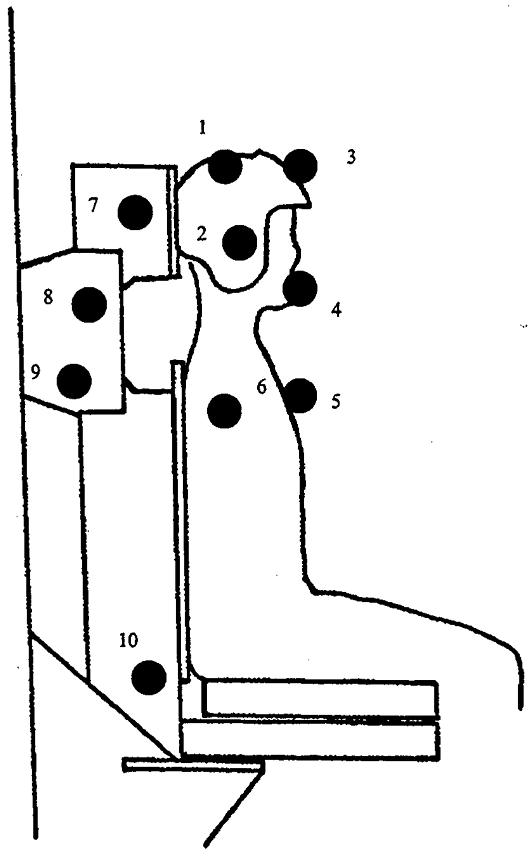


Figure A- 9: Selspot Position Reference Structure

SELSPOT Motion Analysis Target Locations



1. Top of Head
2. Side of Head
3. Front of Head
4. Mouth
5. Chest
6. Tip of Shoulder
7. Top of headrest
8. Upper frame
9. Upper frame
10. Lower frame

Figure A- 10: Selspot LED Target Locations